Nature Conservation 24: 1–20 (2018)
doi: 10.3897/natureconservation.24.20942
http://natureconservation.pensoft.net

RESEARCH ARTICLE

A peer-reviewed open-access journal
Nature Conservation
Launched to accelerate biodiversity conservation

Proposed biodiversity conservation areas: gap analysis and spatial prioritization on the inadequately studied Qinghai Plateau, China

Renqiang Li[1], Ryan Powers[2], Ming Xu[3], Yunpu Zheng[4], Shujie Zhao[5]

1 Key Laboratory of Ecosystem Network Observation and Modeling, Institute of Geographic Sciences and Natural Resources, the Chinese Academy of Sciences, 11A Datun Road, Beijing, 100101, China **2** *Department of Ecology and Evolutionary Biology, Yale University, 165 Prospect Street, New Haven 06520, CT, USA* **3** *Department of Ecology, Evolution and Natural Resources, Rutgers University, New Brunswick, NJ 08901, USA* **4** *School of Water Conservancy and Hydropower, Hebei University of Engineering, Handan 056038, China* **5** *Central University of Finance and Economics, 39 South College Road, Beijing, 100081, China*

Corresponding authors: *Renqiang Li* (renqiangli@igsnrr.ac.cn); *Ming Xu* (mingxu@crssa.rutgers.edu)

Academic editor: *C. Margules* | Received 12 September 2017 | Accepted 4 December 2017 | Published 4 January 2018

http://zoobank.org/D94DE26F-1CC5-455A-83ED-5BA02B923C34

Citation: Li R, Powers R, Xu M, Zheng Y, Zhao S (2018) Proposed biodiversity conservation areas: gap analysis and spatial prioritization on the inadequately studied Qinghai Plateau, China. Nature Conservation 24: 1–20. https://doi.org/10.3897/natureconservation.24.20942

Abstract

Global biodiversity priorities are primarily addressed through the establishment or expansion of conservation areas (CAs). Spatial prioritization of these CAs can help minimize biodiversity loss by accounting for the uneven distribution of biodiversity and conservation considerations (e.g., accessibility, cost, and biodiversity threats). Furthermore, optimized spatial priorities can help facilitate the judicious use of limited conservation resources by identifying cost effective CA designs. Here, we demonstrate how key species and ecosystems can be incorporated into systematic conservation planning to propose the expansion and addition of new CAs in the biodiversity-unique and data-poor region of Qinghai Plateau, China. We combined species distribution models with a systematic conservation planning tool, MARXAN to identify CAs for biodiversity on Qinghai Plateau. A set of 57 optimal CAs (273,872 km^2, 39.3 % of this Province) were required to achieve the defined conservation targets in Qinghai Province. We also identified 29 new CAs (139,216 km^2, 20% of Qinghai Province) outside the existing nature reserve (NRs) that are necessary to fully achieve the proposed conservation targets. The conservation importance of these 29 new CAs was also indicated, with 10 labeled as high priority, 11 as medium priority, and 8 as low priority. High priority areas were more abundant in the eastern and southeastern parts of this region. Our results

suggest that many species remain inadequately protected within the Qinghai Plateau, with conservation gaps in eastern and northwestern regions. The proposed more representative and effective CAs can provide useful information for adjusting the existing NRs and developing the first National Park in China.

Keywords
Conservation planning, conservation area, Qinghai Plateau, spatial prioritization, species distribution model

Introduction

The massive growth in the human population and rapid land-cover change has led to unsustainable exploitation and use of biodiversity resources, exacerbated by climate change, biological invasion and other environmental influences (Rands et al. 2010; Alroy 2015; Luo et al. 2015; Chen et al. 2017). Human-induced environmental changes has caused the sixth extinction of 5–20% species in many biological groups, and scientists estimate that we are now losing species at 100–1,000 times greater than pre-human rates (Pimm et al. 1995; Chapin et al. 2000; Lawton et al. 2005). In order to effectively address human and other environmental impacts on biodiversity, conservation areas (CAs) are widely considered essential for managing species habitats and enhancing ecosystem services (Liu et al. 2003; Carranza et al. 2014; Gray et al. 2016; Zhang et al. 2017). Recognition of this imperative has resulted in the protection of around 15% of Earth's land and 3% of the oceans (Andrew et al. 2012; Gray et al. 2016). However, there is no consensus on the effectiveness of CAs as a conservation tool, and substantial conservation gaps still exist, leaving much the world's remaining biodiversity unprotected (Laurance et al. 2010; Gray et al. 2016).

Most of conservation policies worldwide focus overwhelmingly on expanding the coverage of CA networks to achieve conservation targets. In 2010, 193 parties of the Convention of Biological Diversity (CBD) recommended a new strategic plan to combat global biodiversity decline. A key element of this plan is Aichi target 11, which includes a commitment to expand the global coverage of CAs to at least 17% of terrestrial land and 10% of marine areas by 2020 (Aichi Target 11, CBD 2011; Sanderson et al. 2015). CBD targets, if adhered to, have the potential to spur rapid worldwide expansion of the CA networks (Watson et al. 2014). However, the CA's size does not guarantee desirable conservation outcomes; its effectiveness also depends on where it is located. Thus, there has been a critical need for the strategic expansion of CA networks (Venter et al. 2014). It is important to acknowledge that the planning of CAs is typically understaffed, underfunded, and beleaguered in the face of external threats, so conservation efforts should also be complemented with the appropriate management and planning of existing CAs (Sanderson et al. 2015). Previous calls for enhancing CA management have focused on improving operational effectiveness of each CA. However, little guidance has been offered on how to increase the collective effectiveness for meeting biodiversity conservation goals and improving the performance of CAs (Sanderson et al. 2015).

Species distribution models (SDMs), also commonly referred to as ecological niche models (ENMs), have become a fundamental tool used to spatially predict habitat suitability in ecology, biogeography, and conservation biology (Franklin 2013; Guisan et al. 2013). These SDMs, which rely on ecological theory of processes that mediate species distributions and abundance – especially niche theory (Guillera-Arroita et al. 2015), are currently the main approach for converting individual point-locality data, such as museum collection records (Loiselle et al. 2003; Peterson et al. 2011) into the potential distributional range of a species or predicted ranges following global climate change (Li et al. 2015). Thus, SDMs have the potential to play a critical role in supporting spatial conservation decision making, especially when conservation biologists are often pressed to make recommendations about conserving biodiversity based on limited species-distribution data and biodiversity resources (Addison et al. 2013).

Conservationists may aspire to protect as much of the Earth's remaining biodiversity as possible, but limited conservation resources beget the need for spatial prioritization or the placement of CAs in areas that maximize the greatest return on investment (Carwardine et al. 2009). Systematic conservation-planning approaches help support the judicious use of conservation resources by identifying potential areas that efficiently meet specified conservation targets for the least cost (Margules and Pressey 2000; Carwardine et al. 2008; Linke et al. 2012). In general, systematic conservation approaches also aim to identify priority areas or refugees for ensuring the representation and long-term persistence of biodiversity (Margules et al. 2002; Leslie et al. 2003; Wu et al. 2011; Hermoso and Kennard 2012), and usually include multistep procedures, (1) choosing a set of conservation features (species, ecosystems, or ecosystem services) as surrogates of biodiversity in a region, (2) defining the targets for each of these conservation features, and identifying the conservation gap, (3) assigning a conservation cost to each planning unit in a region, and (4) using conservation planning software to identify priority areas for biodiversity based on meeting the defined conservation goals, increasing landscape connection, and minimizing conservation cost (Fajardo et al. 2014).

Qinghai Province is located in the Qinghai-Tibet Plateau, a globally unique biogeographic area. It has one of the highest concentrations of biodiversity among the high altitude regions in the world, and has also been classified as area of high conservation importance by the Chinese government. To date, the Qinghai Province has established 11 NRs, with a total area of 218,000 km^2, covering 30.2% of the province's land area. Importantly, however, these NRs are reputed to be biased to less economically viable areas (i.e., minimal foregone resource opportunities). Since representation of biodiversity did not drive the selection of these NRs, many species and habitats remain inadequately protected and vulnerable to threatening processes. Due to the lack of biodiversity information, the effectiveness and representation of species conservation in this region has not been systematically explored. Moreover, China is planning the world's biggest National Park in the Qinghai-Tibet Plateau, which is the first National Park in China and will cover some 120,000 square kilometers. The identification of the National Park's boundary represents a substantial challenge to its development. The goals of this study are to: (1) evaluate the ability of existing NRs to contribute to

the overall goal of protecting key species and ecosystems; (2) identify a set of CAs that meet our defined conservation targets, and (3) prioritize these additional CAs outside of the existing NRs in Qinghai Province to provide important information for the creation of National Park.

Materials and methods

Study area

Qinghai Province is situated in the northeast of the Qinghai-Tibet plateau, which is the "water tower" of China and Asia (Huang 2013). Its total area is 7.2×10^4 km^2, one thirteenth of China's total area. It comprises the headwaters of several major Asian rivers, including the Yellow, Yangtze, Mekong, Salween and Yarlung Tsangpo (Brahmaputra) rivers, and thus contributes significantly to the livelihood and wellbeing of nearly 40 percent of the world's population. Therefore, it is important to conserve this region for the livelihoods of all those people. The elevation in the province ranges from 1664 m to 6619 m (Fig. 1). From extensive alpine grasslands and wetlands to forests and deserts, Qinghai is home to a wide variety of globally significant, but fragile ecosystems. As a traditionally sparsely inhabited region with a variety of different climatic zones and natural habitats, Qinghai Province provides important habitats for many endangered species including the Tibetan antelope, wild yak, argali, snow leopard, black necked crane, saker falcon and many other key endangered wild animals.

Conservation features

Efficient expansion of CAs requires simultaneous planning for species and ecosystems (Polak et al. 2015). Qinghai Forestry Department put forward a list of 79 rare and endangered species in 2013 as indicator species of biodiversity conservation in Qinghai Province. We thus used 11 endemic ecosystem types (Table 1) and 72 of the 79 endangered species (Table 2) as the surrogate of biodiversity in this region. In this study, we integrated conservation features from three sources to achieve maximum representation of biodiversity and compensate for limitations in data availability: (1) China key rare and endangered species database collected by The Nature Conservancy's China biodiversity blueprint project. This database has been successfully used to predict climate change induced range shifts of *Galliformes* in China (Li et al. 2010). It was once employed to identify conservation priority areas in "China national biodiversity conservation strategy and action plan (2011–2030)" (Ministry of Environmental Protection 2010); (2) Chinese Endangered Species Information System (CESIS) (Xie et al. 1997). This system collected the latest endangered species information including mammals, birds, reptiles, amphibians, fish species or subspecies in China. Both the theoretical and practical simulations show that when the number of species presence

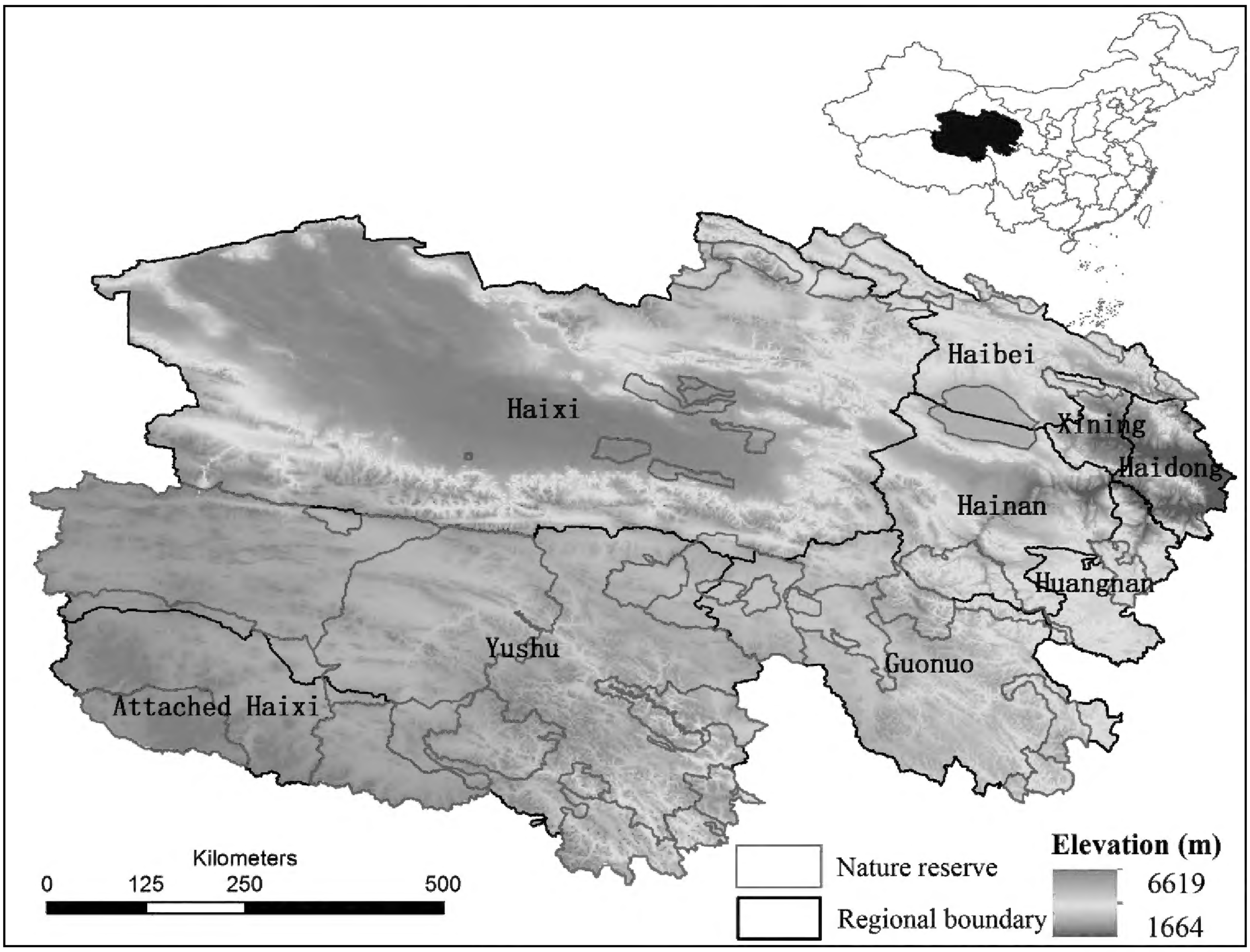

Figure 1. The location of Qinghai Province in China and the elevation range.

points is greater than 14, the species distribution model can produce a better simulation result of species habitat (Proosdij et al. 2015). Therefore, we excluded these species with less than 15 presence points from the two databases, and obtained species presence data for 59 key rare and endangered species (Table 2). We checked the independence of the records and used them to input species distribution models to simulate their geographic ranges; (3) We identified the other 13 species' suitability range using expert range maps from the online IUCN website (Table 2).

Species distribution modelling

We applied a maximum entropy modelling technique with the MAXENT software (Phillips et al. 2006) to predict the graphic distributions of the 59 endangered species. This approach has been extensively adopted to project species range shifts and change in species diversity patterns and to inform conservation planning (Hernandez et al. 2008; Costa et al. 2010; Ponce-Reyes et al. 2012; McPherson 2014). A set of 19 bioclimatic variables at 30s resolution were collected from the WorldClim dataset for current conditions (average for 1951–2000) (Hijmans et al. 2005). We performed a principal components analysis of 19 bioclimatic variables to select the first three principal com-

Table 1. Conservation targets for regional endemic or endemic ecosystems to China in Qinghai Province.

Vegetation name	Endemism	Conservation target (%)
Carex moorcroftii Steppe	Regional endemic	15
Kobresia humilis Alpine meadow	Regional endemic	15
Alpine kobresia Meadow	Regional endemic	15
Kobresia capillifolia Alpine meadow	Regional endemic	15
Populus euphratica Forest	Regional endemic	10
Picea balfouriana Forest	Endemic to China	10
Picea purpurea Mast Forest	Endemic to China	10
Picea asperata var. *ponderosa* Forest	Endemic to China	10
Abies fabri (Mast.) Craib	Endemic to China	10
S. convallium Forest	Endemic to China	10
Qinghai spruce Forest	Endemic to China	10

Table 2. Summary of species data source, the proposed conservation goal of each species according to their current conservation status, spatial distribution size and endemic status, and species representation (percentage protected) in the current nature reserve network of Qinghai Province based on the conservation goals defined in this study.

Scientific name	Record points	Target (%)	Percentage protected (%)
Pseudois nayaur	183	5	40
Gypaetus barbatus	52	5	36
Ithaginis cruentus	85	5	35
Tetraogallus tibetanus	55	15	41
Aquila heliaca	34	20	44
Otocolobus manul	144	5	29
Moschus chrysogaster	116	15	33
Mustela altaica	171	10	26
Crossoptilon auritum	72	10	25
Lynx lynx	269	7	22
Martes foina	140	5	19
Tetraogallus himalayensis	43	6	19
Gervus albirostris	195	20	32
Grus nigricollis	111	20	32
Marmota himalayana	95	5	17
Buteo hemilasius	179	13	21
Haliaeetus leucoryphus	75	15	23
Bos mutus	104	25	32
Equus kiang	79	25	32
Pantholops hodgsonii	133	25	32
Ailurus fulgens	319	34	37
Falco cherrug	48	29	32
Pandion haliaetus	77	24	26
Procapra picticaudata	123	33	33
Ovis ammon	130	17	17

Scientific name	Record points	Target (%)	Percentage protected (%)
Aegypius monachus	225	16	15
Canis lupus	506	23	22
Panthera uncia	161	30	28
Bonasa sewerzowi	31	27	25
Gyps himalayensis	96	19	17
Antropoides virgo	105	11	8
Cygnus olor	41	13	10
Capricornis rubidus	504	28	24
Ursus thibetanus	225	29	24
Grus grus	110	14	9
Cervus unicolor	318	31	25
Accipiter nisus	297	35	27
Lophophorus lhuysii	47	39	30
Aquila nipalensis	105	21	11
Gazella subgutturosa	94	16	4
Cygnus cygnus	128	18	6
Falco peregrinus	77	23	9
Cervus elaphus	246	39	25
Lutra lutra	552	28	14
Falco subbuteo	91	25	11
Ciconia nigra	277	24	9
Milvus lineatus	344	23	6
Falco tinnunculus	248	25	8
Otis tarda	122	24	5
Cuon alpinus	207	31	11
Chrysolophus pictus	503	28	8
Pelecanus onocrotalus	16	23	3
Mustela sibirica	573	25	4
Vulpes vulpes	718	25	3
Macaca mulatta	653	30	5
Panthera pardus	425	49	21
Neofelis nebulosa	292	35	0
Andrias davidianus	185	54	1
Strix uralensis	Range map	25	100
Circus cyaneus	Range map	5	32
Bubo bubo	Range map	5	32
Athene noctua	Range map	5	32
Ursus arctos	Range map	5	31
Accipiter nisus	Range map	7	25
Aquila chrysaetos	Range map	12	29
Procapra przewalskii	Range map	60	68
Moschus berezovskii	Range map	29	33
Haliaeetus albicilla	Range map	18	13
Asio otus	Range map	23	14
Felis bieti	Range map	29	19
Platalea leucorodia	Range map	24	0

ponents as input climatic variables for our SDMs. We also included vegetation types and two human disturbance factors (population density and gross domestic product) into model input layers.

MAXENT was run in default settings with a maximum of 500 iterations. We used cross-validation procedures to model calibration, which randomly assigned 75% of species records while keeping the other 25% records for AUC computations. We assessed model performance with AUC, which provides a single measure of model performance and ranges from 0.5 (randomness) to 1 (perfect discrimination), where a score higher than 0.7 is considered a good model performance (Rebelo et al. 2010). Outputs from MAXENT models were reclassified to presence/absence predictions using the "Maximum Training Sensitivity Plus Specificity" threshold, which has proven to generally produce more accurate results than other thresholds (Fajardo et al. 2014; Liu et al. 2005).

The targets of conservation features

We defined conservation targets for each species according to the current conservation status, spatial distribution range and endemic status (Fajardo et al. 2014). The target for each species was calculated as the sum of the following three indices: conservation status index, distribution size index, and conservation endemic index.

Distribution size index: Species with smaller distribution area should have a higher conservation priority and target, whereas species with larger distribution area should have lower a conservation target (Rodrigues et al. 2004). We assigned a more demanding representation target to species with more restricted ranges, acknowledging the negative relationship between species distribution size and extinction risk (Gaston and Rodrigues 2003). The value given to each species was scaled between a minimum coverage of 5% for species with a distribution equal to or greater than 300,000 km^2 in Qinghai Province, and a maximum of 25% for species with ranges equal to or less than 1,000 km^2 (Rodrigues et al. 2004). The 300,000 km^2 upper threshold corresponds to the range size observed in one third of the studied species in Qinghai Province.

Conservation status index: Like in Fajardo et al. (2014), we assigned goals to species identified as threatened by the IUCN following a decreasing scale: Critically Endangered (CR), 25%; Endangered (EN), 17.5%; Vulnerable (VU), 10%; Near Threatened (NT), 5%; Least Concern (LC), Not Evaluated (NE), and Data Deficient (DD), 0%.

Conservation endemic index: An endemic species is one whose habitat is restricted to a particular area, and can be easily under threat. As such, endemic species are of great conservation interest to conservation planning. We assigned goals of 10% for species endemic to Qinghai-Tibet Plateau, 5% for endemic species in China, and 0 for other species.

In Qinghai Province, wetland, forest and endemic grassland ecosystems have high conservation importance. Existing NRs already protect 70% of the important

plateau wetland ecosystem (Liu and Li 2007). Therefore, we exclusively focused on endemic grassland and unique forest ecosystems. We used vegetation map of China (1:1 000 000) to represent ecosystem features of this region, and selected 11 endemic vegetation types as key conservation ecosystem types according to their endemism in this region or China (Qu 2011). We identified their conservation target as 10% for ecosystems endemic to the Qinghai-Tibet Plateau, 5% for endemic ecosystems in China, and 0 for other ecosystems. Although the conservation targets were determined arbitrarily, the results from our scenarios indicated that the changed conservation targets for each conservation feature did not radically affect the spatial distribution of the proposed CAs.

Species representation within the existing nature reserves

We performed a gap analysis that compared the defined conservation targets to species' current representation within existing NRs. The species distributions and expert range maps were first intersected with the NRs, and then the percentage of its distribution within NRs was calculated and compared with its defined conservation targets. Species are considered insufficiently protected by the current NRs when the percentage is below their conservation targets.

Proposed conservation priority areas

We used the systematic conservation planning software MARXAN 2.4.3 (Ball et al. 2009) to identify the most efficient set of conservation priority areas to meet the above targets for both ecosystems and endangered species. It is a decision-support tool, which solves an optimization problem of representing a set of conservation features (species, ecosystems, ecoregions or ecosystem services) at a minimal cost, and has been widely used for identifying CAs in China (Wu et al. 2014; Zhang et al. 2014) and across the world (Powers et al. 2013; Hermoso et al. 2013; Tulloch et al. 2016; Powers et al. 2016). The Qinghai Province was partitioned into 4 km × 4 km grids or 44,475 planning units (PUs). We unlocked Kekexili National NR and the Soka River Protection zone of Sanjiangyuan National NR, the two largest NRs of current network, and set PUs in them as "available", because we assumed that the large extent of these two NRs may not be required to effectively meet conservation targets. PUs coinciding with other current NRs were prioritized in the MARXAN solutions. We set the cost of each PU as the value of the human footprint index (Sanderson et al. 2002). This index assumed that PUs with less human disturbance have higher social acceptance (Powers et al. 2013) and a lower conservation cost, and is widely accepted as a universal conservation cost surrogate (Fajardo et al. 2014; Wu et al. 2014). We ran different scenarios using the Zonae Cogito Decision Support System to test the most suitable parameters for MARXAN whereby we varied the boundary length modifier (BLM) and the species

penalty factor (SPF). BLM and SPF were optimized to 100 and 1 respectfully since it offered an efficient tradeoff in our scenario analysis between cost, reserve compactness and achieving conservation targets. We ran MARXAN to identify 100 solutions using the simulated annealing algorithm and the default values for number of iterations (1,000,000) and temperature Decreases (10,000).

The best solution from the MARXAN output is the network most optimized with respect to achieving the conservation targets at the lowest cost. We thus proposed priority areas from MARXAN's best solution. Given the financial challenges associated with the immediate implementation of these areas proposed in the best solution, we prioritized the areas outside of existing NRs according to three important decision making criteria: species richness, selection frequency, and vulnerability. Species richness was generated by calculating the number of studied species present in each 4 km×4 km grid cell across the entire study region based on the binary distribution maps from species distribution models and the range maps. It has long been recognized as a key characteristic determining biodiversity patterns and conservation selection. The grid cells with higher richness were assumed to have higher conservation value and were preferentially prioritized. MARXAN produced 100 solutions and a summed solution made up of the selection frequency across the 100 runs. This score of selection frequency represents the total section frequency of each grid. The vulnerability criteria is used to prioritize highly impacted areas that are in greater need of protection. We should give priority to protecting areas where human disturbance is more serious and ecologically more sensitive. To calculate the score, we used the human footprint index as a measure of the human influence on each PU.

The three criteria scores were normalized to values between 0 and 100, and summed to give each proposed CA an overall priority score. Priority areas were classified as high, medium, and low priority according to the overall priority score. The area of high, medium, and low priority was determined using natural break method (Fajardo et al. 2014).

Results

Spatial patterns of species richness in Qinghai Province

The species distribution models were able to accurately predict the geographic distributions of the species. Specially, the models had AUC values between 0.843 and 0.999, which indicates that the generated geographic distributions can be used to estimate regional species richness patterns and conservation planning (Fig. 4a). Species richness was spatially heterogeneous and follows the well-known latitudinal pattern in Qinghai Province. Its spatial pattern shows a general reduction from the eastern to western areas. The maximum value of 57 species per km^2 is located in the Haidong and Xining regions. Regions with a relatively low number of species are situated in the western high altitude areas, including Haixi and Yusu (Fig. 4a).

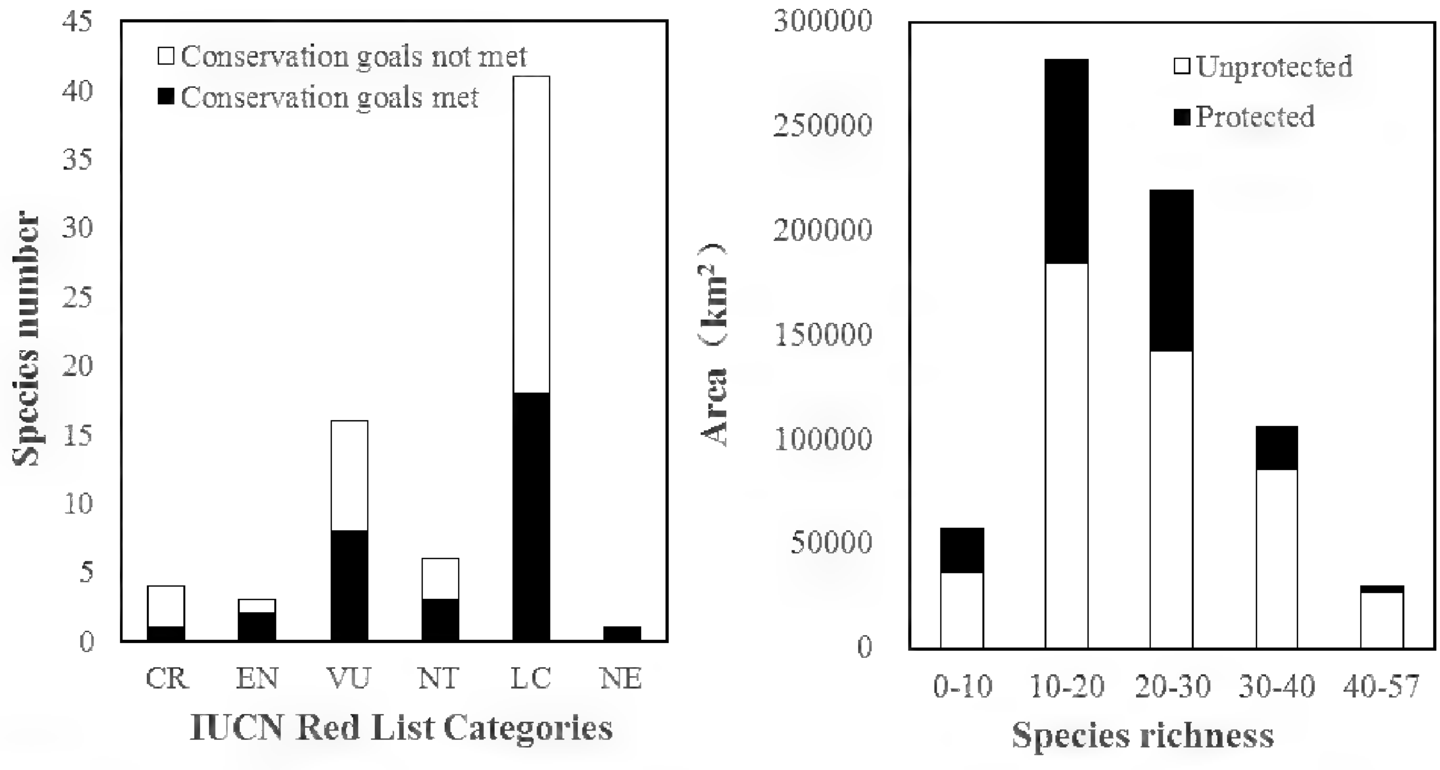

Figure 2. Summary of the conservation gap for key rare and endangered species in Qinghai Province: (a) species number of conservation goals met and not met; (b) the area protected and unprotected in nature reserves (CR – Critically Endangered, EN – Endangered, VU – Vulnerable, NT – Near Threatened, LC - Least Concern).

Conservation effectiveness in the current NRs

The 11 NRs account for 30.2% of the total Qinghai Province area. The percentage of area with 10–20 and 30–40 species/km^2 protected by the current NRs was 37% and 35%. The two regions with the highest species richness encompassed an area of 110000 km^2 and 3000 km^2 respectively, and had a low protection level of 19% and 11% (Fig. 1). These two regions are mainly located in the farming-pastoral ecotone within the eastern and southern parts of Qinghai Province.

We found that 41 species, 53% of the total, are insufficiently protected in the current reserve system according to our defined conservation target for each species. We also found that targets for those species most at risk species are not well met under current NRs: 3 out of 4 critically endangered, on third of the endangered, and 8 out of 16 vulnerable species did not achieve their defined conservation goals (Fig. 2). There were 22 and 11 species whose protection under existing NRs exceeded conservation targets by 10% and 20% respectively (Fig. 2).

Proposed priority areas for biodiversity conservation

A set of priority areas based on the best solution were selected in Qinghai Province (Fig. 3). We identified 57 optimal CAs for biodiversity conservation in Qinghai Province. The total area assigned as CAs in order to achieve the conservation targets for all conservation features is about 273,872 km^2, about 39.3 % of the total land area

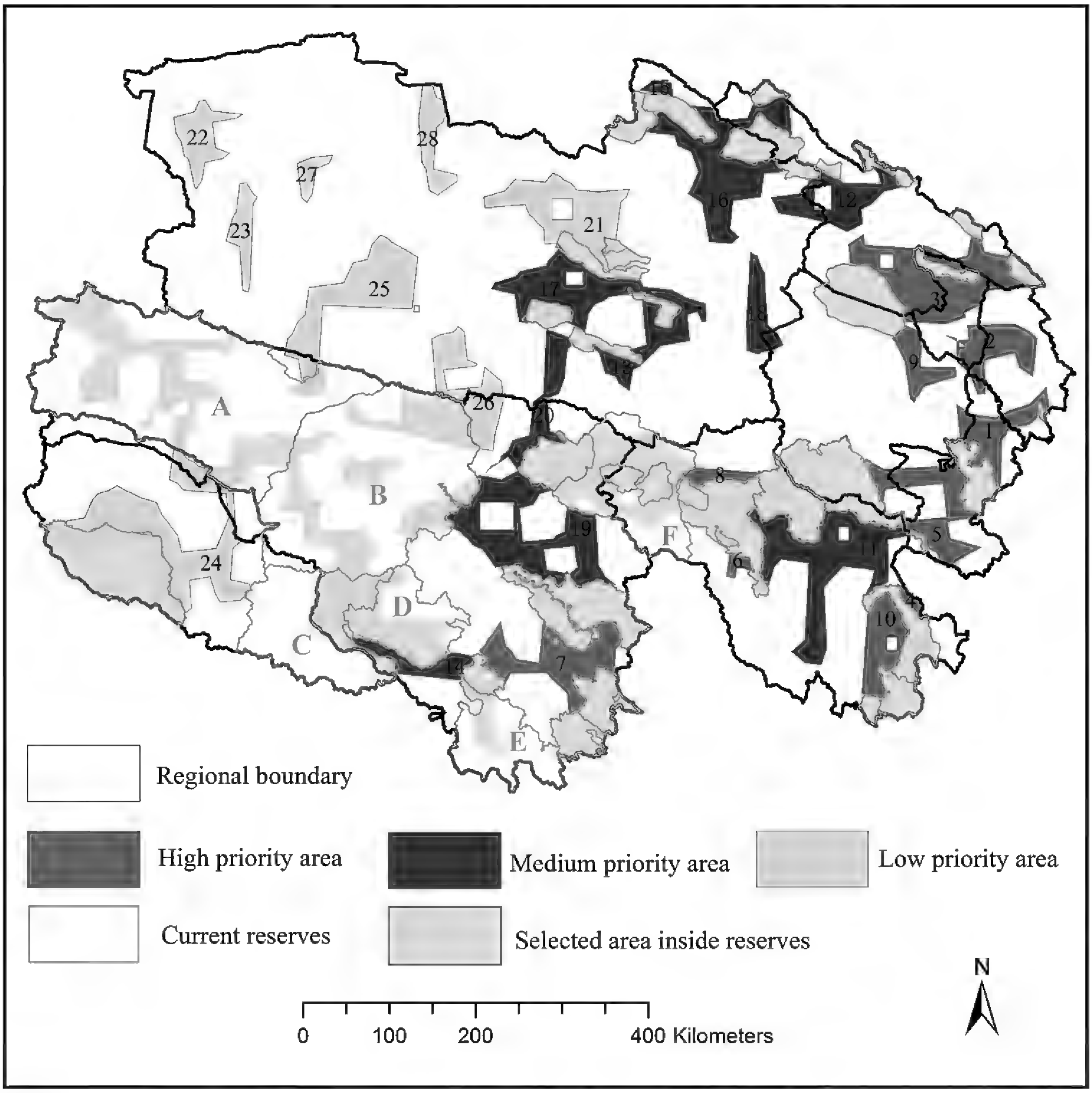

Figure 3. Spatial distribution of proposed priority areas (including high, medium and low priorities) inside and outside the existing nature reserves for Qinghai Province.

in Qinghai Province. Among these selected priority areas, 28 areas are located within the existing NRs. The total area of selected CAs inside current reserves is about 134,656km^2, 19.3% of Qinghai Province. In order to better guide conservation investment and management, we judiciously reduced the coverage of the Sanjiangyuan National NR (conservation zone A, B, C and D in Fig. 3). This very large protected area was not optimized; therefore, its conservation effectiveness (e.g., reduced conservation cost, greater transparency and objectiveness, and higher level of protection for more species) can be improved by systematic conservation planning.

To fully meet our criteria for our conservation features, 29 new or not previously conserved areas, approximately 139,216 km^2 (20% of Qinghai Province), were added to the current NR system (Fig. 3). The majority of these new conservation priority

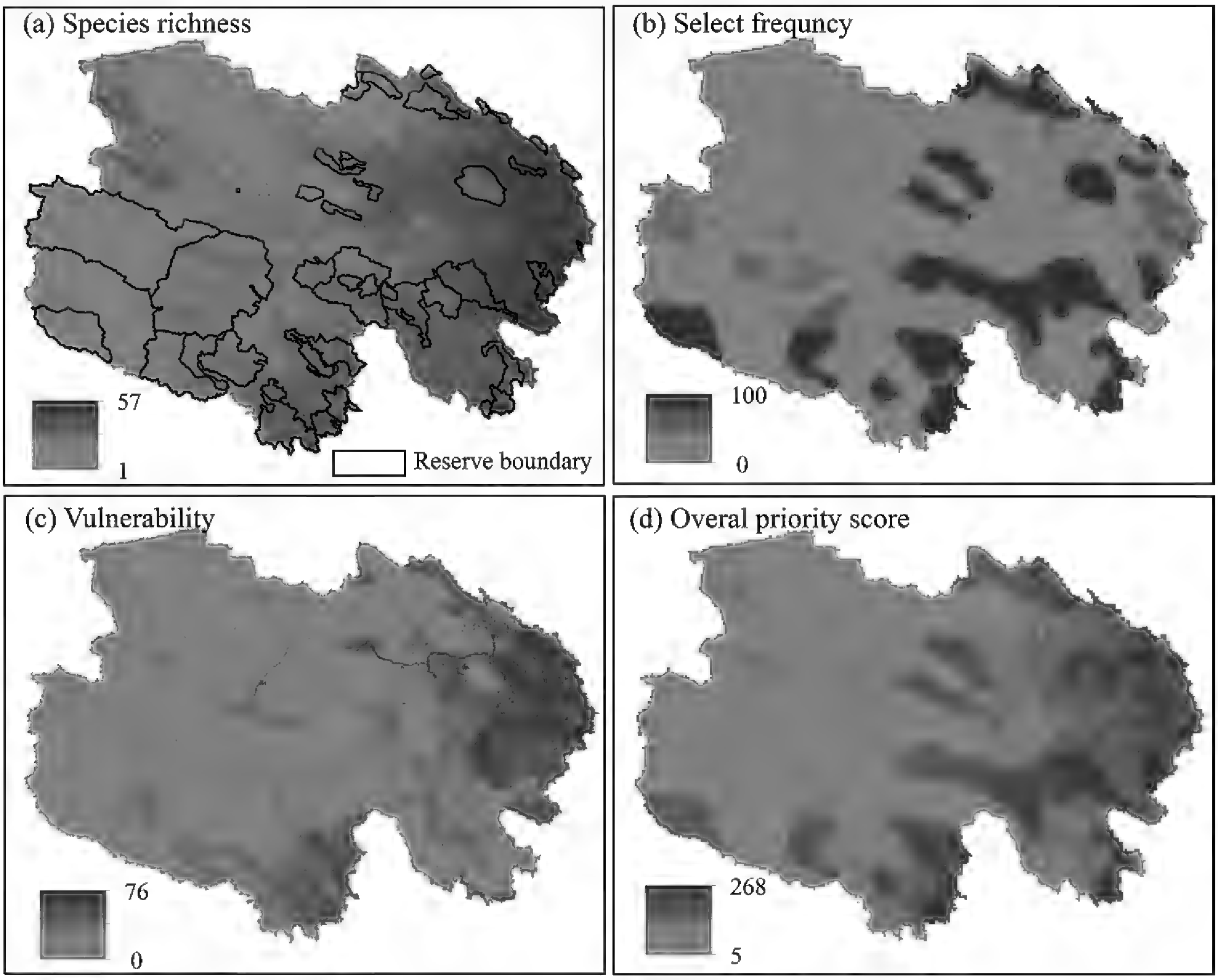

Figure 4. Spatial distribution maps for the three criteria used to evaluate the conservation priority of the proposed conservation areas in this study: **a** species richness and current nature reserves across Qinghai Province **b** vulnerability, derived from the Human Footprint index **c** selection frequency of the planning units, including additional solutions with varying conservation goals; and **d** overall priority score.

areas were located in the Qinghai Province's east and, to a lesser degree, in parts of the central and southern regions. Some conservation priorities were selected to improve the connectivity among other conservation areas, which were located between Qinghai Qaidam Haloxylon ammodendron forest national NR and Qinghai Nuomuhong Provincial NR (13, 17, and 20 in Fig. 3), Protection Zones of Sanjiangyuan National NR (7 and14 in Fig. 3), and Protection Zones of Qilian Mountain National NR (12 and 16 in Fig. 3).

The prioritization of additional conservation areas

The prioritization of new selected areas outside the existing NRs was determined according to an overall priority score derived from three design criteria: species richness, selection frequency, and vulnerability. The vulnerability of the proposed priority areas, as measured by the vulnerability score, increases gradually from east to west. Of the

29 new areas, 10 were designated as high priority, 11 as medium priority, and 8 as low priority (Fig. 3). High priority areas are more abundant in the eastern and southeastern parts of this province. In general, five additional priority areas were larger than 1000 km^2, while 11 are larger than 5,000 km^2 in size. For the top five largest priority areas, two are in the northeastern region, while three are in the south of Qinghai Province. The largest one (24 in Fig. 3) was the attached Haixi in the southwest of Qinghai (11135 km^2). The second largest (11 in Fig. 3) was in the central part of Guoluo (106906 km^2), the third (19 in Fig. 3) was in the east of Yusu (9989 km^2), while the fourth (3 in Fig. 3) and the fifth (16 in Fig. 3) are located in between Haibei and Xining (9802 km^2) and between Haibei and Haixi (9437 km^2), respectively.

Discussion

To the best of our knowledge, the work described here, is the first time a systematic approach to biodiversity conservation planning has been devised for the Qinghai Province. Our approach focused on the conservation of both species and ecosystem-level features, and builds upon the current NR network to highlight new areas for protection. Other similar studies have demonstrated that, when expanding existing NRs, fewer resources and less land are required to achieve conservation targets if species and ecosystem conservation features are addressed at the same time (Lombard et al. 2003; Polak et al. 2015). By avoiding the selection of planning units that become redundant once a secondary goal is added, the simultaneous inclusion of multiple conservation feature types can lead to final CA solutions that are likely smaller and less costly. Complementarity is a key consideration when planning for conservation (Watson et al. 2008), and assessing this complementarity for Qinghai Province could potentially inform planning for expanding and improving the current conservation system. Our results show the biodiversity conservation gap and spatial distribution of key conservation areas within the Qinghai Province, and can provide an important basis for the assessment and adjustment of regional conservation planning in the future.

The existing and extensive NR network in Qinghai Province plays an important role in maintaining unique endangered species and key ecosystems. However, our results suggest that additional protection is still required. First, the eastern and southeastern parts of Qinghai Province are key areas for biodiversity conservation. These areas are rich in rare and endangered species distributions, but are currently under protected. Further, in many instances the largely unprotected areas surrounding high population densities may warrant additional conservation emphasis, despite greater risks for land-use conflict and implementation challenges, as they typically contain greater diversity, species of concern and have the potential to constrain environmental impacts associated with human activities. New NRs are also recommended for the Qaidam basin of Haixi Mongolian Autonomous Prefecture, which contains no NRs and is home to

many species of high conservation value that are unique to these desert ecosystems. In addition, we recommend that the boundaries of some current NRs be adjusted according to the distribution of conservation features. Considerable conservation gains can be achieved if the NR boundaries of Sanjiangyuan Tongtianhe protection division, Angsai protection division, and Mengda and the Xianmi NR are modified to improve the conservation efficiency.

Expanding the proportion of land protected will not guarantee the improvement of conservation effectiveness and representation, and could prove extremely costly. A systematic conservation approach, such as the one presented in this study, provides a useful framework that can help guide planners as to where (spatially) conservation efforts should be targeted to efficiently achieve conservation objectives. Over the last two decades, the number and area of NRs have greatly increased in China. In 2014, there were 2,729 NRs, accounting for about 15% of China's land territory, ann more than 30.2% in Qinghai. Since NRs hold the majority of the country's wildlife, they play a fundamental role in protecting regional biodiversity. Nonetheless, many threatened species are still not adequately protected. Key biodiversity areas, which are the most important sites for biodiversity conservation, are also poorly represented in existing NRs. The effectiveness of many NRs in China is compromised by lack of ongoing financial and technical support, systematic planning and an adequate conceptual base to optimize the conservation performance. The NR system faces serious challenges. We need to act quickly to shift the focus of the construction and management of NRs from quantitative growth to quality improvement, and incorporate systematic planning into conservation practices, because global change and other threats are quickly eroding biodiversity. Unless this is done, we risk many NRs becoming "paper parks"— existing in name only (Di and Toivonen 2015).

Designing and complementing conservation networks to safeguard biodiversity is a difficult task for governments and conservationists in a plateau due to the absence of information regarding species distributions, density or abundance. In this study, we adopted species distribution models (SDMs) to simulate the ranges of key rare and endangered species. These species are largely considered the best available proxy of biodiversity in Qinghai Province. SDMs are increasingly proposed to support conservation decision making, and have the potential to better bridge theory and practice, and contribute to improve both scientific knowledge and conservation outcomes when the ecological knowledge is incomplete, such as in Qinghai plateau. Although the set of 72 key endangered species used in this study as indicator species is not exhaustive and not devoid of uncertainty, the high consistency of our overall results suggest that they are consistent with currently described biodiversity patterns in Qinghai Province. Looking forward, the funding and capacity for collecting more adequate species data and keeping them up to date are critical to future conservation efforts and reducing biodiversity loss (Wu 2016). As a result, there is an immediate need to further increase funding for biodiversity data collection and capacity building, particularly in biodiversity-unique, data-poor Qinghai Province.

Acknowledgements

We are grateful to many colleagues at Institute of Geographic Sciences and Natural Resources, CAS, Forestry Department of Qinghai Province, and the State Forestry of Administration for their assistance in the data collection and processing. We especially thank Dr. Li Xinhai for the assistance in data collections. This study was funded by Forestry Science and Technology Demonstration Project (2017): Cobenefits between biodiversity conservation and carbon storage in Huangshui National Wetland Park, Program for developing unique institute of the Chinese Academy of Sciences (TSYJS05), The UNDP/GEF Qinghai Biodiversity Conservation Project, and the Natural Science Foundation of China (31400418).

References

Addison PFE, Rumpff L, Bau SS, Carey JM, Chee YE, Jarrad FC, Burgman MA (2013) Practical solutions for making models indispensable in conservation decision-making. Diversity and Distribution 19: 490–502. https://doi.org/10.1111/ddi.12054

Alroy J (2015) Current extinction rates of reptiles and amphibians. Proceedings of the National Academy of Sciences of the United States of America 112: 13003–13008. https://doi.org/10.1073/pnas.1508681112

Andrew ME, Wulder MA, Coops NC (2012) Identification of de facto protected areas in boreal Canada. Biological Conservation 146: 97–107. https://doi.org/10.1016/j.biocon.2011.11.029

Ball IR, Possingham HP, Watts M (2009) Marxan and relatives:software for spatial conservation prioritisationIn Spatial conservation prioritisation:quantitative methods and computational tools. Oxford University Press, Oxford, 185–195.

Carranza T, Balmford A, Kapos V, Manica A (2014) Protected area effectiveness in reducing conversion in a rapidly vanishing ecosystem: the Brazilian cerrado. Conservation Letters 7: 216–223. https://doi.org/10.1111/conl.12049

Carwardine J, Wilson KA, Ceballos G, Ehrlich PR, Naidoo R, Lwamura T, Possingham HP (2008) Cost effective priorities for global mammal conservation. Proceedings of the National Academy of Sciences of the United States of America 105: 11446–11450. https://doi.org/10.1073/pnas.0707157105

Carwardine J, Klein CJ, Wilson KA, Pressey RL, Possingham HP (2009) Hitting the target and missing the point:target-based conservation planning in context. Conservation Letters 2: 3–10. https://doi.org/10.1111/j.1755-263X.2008.00042.x

Chapin FS, Zavaleta ES, Eviner VT, Naylor RL, Vitousek PM et al. (2000) Consequences of changing biodiversity. Nature 405: 239–242. https://doi.org/10.1038/35012241

Chen YH, Zhang J, Jiang JP, Nielsen SE, He FL (2017) Assessing the effectiveness of China's protected areas to conserve current and future amphibian diversity. Diversity and Distributions 23: 146–157. https://doi.org/10.1111/ddi.12508

Costa GC, Nogueira C, Machado RB, Colli GR (2010) Sampling bias and the use of ecological niche modeling in conservation planning: a field evaluation in a biodiversity hotspot. Biodiversity Conservation 19: 883–899. https://doi.org/10.1007/s10531-009-9746-8

Diminin E, Toivonen T (2015) Global protected area expansion: creating more than paper parks. Bioscience 65: 637–638. https://doi.org/10.1093/biosci/biv064

Fajardo J, Lessmann J, Bonaccorso E, Devenish C, Munoz J (2014) Combined use of systematic conservation planning, species distribution modelling, and connectivity analysis reveals severe conservation gaps in a Megadiverse Country (Peru) PLoS ONE 9: e114367. https://doi.org/10.1371/journal.pone.0114367

Franklin J (2013) Species distribution models in conservation biogeography:developments and challenges. Diversity and Distributions 19: 1217–1223. https://doi.org/10.1111/ddi.12125

Gaston KJ, Rodrigues ASL (2003) Reserve selection in regions with poor biological data. Conservation Biology 17: 188–195. https://doi.org/10.1046/j.1523-1739.2003.01268.x

Gray CL, Hill SLL, Newbold T, Hudson LN, Börger L et al. (2016) Local biodiversity is higher inside than outside terrestrial protected areas worldwide. Nature Communications 7: 12306. https://doi.org/10.1038/ncomms12306

Guisan A, Tingley R, Baumgartner JB, Naujokaitis-Lewis L, Sutdiffe PR, Brotons L et al. (2013) Predicting species distributions for conservation decisions. Ecology Letters 16: 1424–1435. https://doi.org/10.1111/ele.12189

Guillera-Arroita G, Lahoz-Monfort JJ, Elith J, Gordon A, Kujala H (2015) Is my species distribution model fit for purpose? Matching data and models to applications. Global Ecology and Biogeography 24: 276–292. https://doi.org/10.1111/geb.12268

Hermoso V, Kennard MJ (2012) Uncertainty in coarse conservation assessments hinders the efficient achievement of conservation goals. Biological Conservation 147(1): 52–59. https://doi.org/10.1016/j.biocon.2012.01.020

Hermoso V, Ward DP, Kennard MJ (2013) Prioritizing refugia for freshwater biodiversity conservation in highly seasonal ecosystems. Diversity and Distributions 19: 1031–1042. https://doi.org/10.1111/ddi.12082

Hernandez PA, Franke I, Herzog SK, Pacheco V, Paniagua L, Quintana HL, Soto A, Swenson JJ, Tovar C, Valqui TH, Vargas J, Young BE (2008) Predicting species distributions in poorly-studied landscapes. Biodiversity Conservation 17: 1353–1366. https://doi.org/10.1007/s10531-007-9314-z

Hijmans RJ, Cameron SEJ, Parra L, Jones PG, Jarvis A (2005) Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965–1978. https://doi.org/10.1002/joc.1276

Huang YP (2013) Managing the Three-Rivers Headwater Region, China: From ecological engineering to social engineering. Ambio 42: 566–576. https://doi.org/10.1007/s13280-012-0366-2

Laurance WF, Useche DC, Rendeiro JR, Kalka M, Bradshaw C et al. (2012) Averting biodiversity collapse in tropical forest protected areas. Nature 489: 290–294. https://doi.org/10.1038/nature11318

Lawton JH, May RM (2005) Extinction Rates, Oxford University Press, Oxford.

Loiselle BA, Howell CA, Graham GH, Goerck JM, Brooks TM, Smith KG, Williams PH (2003) Avoiding pitfalls of using species distribution models in conservation planning. Conservation Biology 17: 1591–1600. https://doi.org/10.1111/j.1523-1739.2003.00233.x

Li RQ, Xu M, Wong MHG, Qiu S, Li XH, Ehrenfeld D, Li DM (2015) Climate change threatens giant panda protection in the 21st century. Biological Conservation 182: 93–101. https://doi.org/10.1016/j.biocon.2014.11.037

Li RQ, Tian HD, Li XH (2010) Climate change induced range shifts of Galliformes in China. Integrative Zoology 1: 153–162.

Liu C, Berry PM, Dawson TP, Pearson RG (2005) Selecting thresholds of occurrence in the prediction of species distributions. Ecography 28: 385–393. https://doi.org/10.1111/j.0906-7590.2005.03957.x

Liu JG, Ouyang ZY, Pimm SL, Raven PH, Wang XK, Miao H, Han NY (2003) Protecting China's biodiversity. Science, 300: 1240–1241. https://doi.org/10.1126/science.1078868

Liu MC, Li DQ (2007) Study on biodiversity conservation priorities: Taking Sanjiangyuan Region. Journal of Natural Science of Hunan Normal University 30: 110–115. [In Chinese with English abstract]

Lombard AT, Cowling RM, Pressey RL, Rebelo AG (2003) Effectiveness of land classes as surrogates for species in conservation planning for the Cape Floristic Region. Biological Conservation 112: 45–62. https://doi.org/10.1016/S0006-3207(02)00422-6

Luo ZH, Jiang ZG, Tang SH (2015) Impacts of climate change on distributions and diversity of ungulates on the Tibetan Plateau. Ecological Applications 25: 24–38. https://doi.org/10.1890/13-1499.1

Margules CR, Pressey RL (2000) Systematic conservation planning. Nature 405: 243–253. https://doi.org/10.1038/35012251

McPherson TY (2014) Landscape scale species distribution modeling across the Guiana Shield to inform conservation decision making in Guyana. Biodiversity Conservation 23: 1931–1948. https://doi.org/10.1007/s10531-014-0696-4

Ministry of Environmental Protection of the People's Republic of China (2011) The Strategy and Action Plan for Biodiversity Protection in China (2011–30), China Environmental Science Press, Beijing. [In Chinese with English abstract]

Pearson R, Raxworthy C, Nakamura M, Peterson A (2007) Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. Journal of Biogeography 34: 102–117. https://doi.org/10.1111/j.1365-2699.2006.01594.x

Phillips SJ, Anderson RP, Schapire RE (2006) Maximum entropy modeling of species geographic distributions. Ecological Modelling 190: 231–259. https://doi.org/10.1016/j.ecolmodel.2005.03.026

Pimm SL, Russell GJ, Gittleman JL, Brooks TM (1995) The future of biodiversity. Science 269: 347–350. https://doi.org/10.1126/science.269.5222.347

Polak T, Watson JEM, Fuller RA, Joseph LN, Martin TG, Possingham HP, Venter O, Carwardine J (2015) Efficient expansion of global protected areas requires simultaneous planning for species and ecosystems. Royal Society Open Science 2: 150107. https://doi.org/10.1098/rsos.150107

Ponce-Reyes R, Reynoso-Rosales VH, Watson JEM, VanDerWal J, Fuller RA, Pressey R, Possingham HP (2012) Vulnerability of cloud forest reserves in Mexico to climate change. Nature Climate Change 2: 448–452. https://doi.org/10.1038/nclimate1453

Powers RP, Coops NC, Nelson T, Wulder MA, Drever CR (2013) Integrating accessibility and intactness into large-area conservation planning in the Canadian boreal forest. Biological Conservation167: 371–379. https://doi.org/10.1016/j.biocon.2013.08.032

Powers RP, Coops NC, Tulloch VJ, Gergel SE, Nelson TA, Wulder MA (2016) A conservation assessment of canada's boreal forest incorporating alternate climate change scenarios. Remote Sensing in Ecology and Conservation. https://doi.org/10.1002/rse2.3

Proosdij ASJV, Sosef MSM, Wieringa JJ, Raes N (2015) Minimum required numbers of specimen records to develop accurate species distribution models. Ecography 39: 542–552. https://doi.org/10.1111/ecog.01509

Qu Y (2011) Conservation planning of biodiversity in the three rivers headwater Region in Qinghai Province. Thesis, Beijing Forestry University. [In Chinese with English abstract]

Rands MRW, Adams W, Bennun L, Butchart SHM, Clements A, Coomes D, Vira B (2010) Biodiversity Conservation: Challenges Beyond 2010. Science 329: 1298–1303. https://doi.org/10.1126/science.1189138

Rebelo H, Tarrosow P, Jones G (2010) Predicted impact of climate change on European bats in relation to their biogeographic patterns. Global Change Biology 16: 561–576. https://doi.org/10.1111/j.1365-2486.2009.02021.x

Rodrigues ASL, Akçakaya HR, Andelman SJ, Bakarr MI, Boitani L (2004) Global gap analysis: Priority regions for expanding the global protected-area network. Bioscience 54: 1092–1100. https://doi.org/10.1641/0006-3568(2004)054[1092:GGAPRF]2.0.CO;2

Rodrigues ASL, Akcakaya HR, Andelman SJ, Bakarr MI, Boitani L, Brooks TM et al. (2004) Global Gap Analysis: Priority regions for expanding the global protected-area network. Bioscience Reports 54: 1092–1100. https://doi.org/10.1641/0006-3568(2004)054[1092:GGAPRF]2.0.CO;2

Sanderson E, Segan DB, Watson JEM (2015) Global status of and prospects for protection of terrestrial geophysical diversity. Conservation Biology 29: 649–656. https://doi.org/10.1111/cobi.12502

Sanderson EW, Jaiteh M, Levy MA, Redford KH, Wannebo AV (2002) The human footprint and the last of the wild. Bioscience 52: 891–904. https://doi.org/10.1641/0006-3568(2002)052[0891:THFATL]2.0.CO;2

Tulloch VJD, Brown CJ, Possinghama HP, Jupiter SD, Maina JM (2016) Improving conservation outcomes for coral reefs affected by future oil palm development in Papua New Guinea. Biological Conservation 203: 43–54. https://doi.org/10.1016/j.biocon.2016.08.013

Venter O, Fuller RA, Segan DB, Carwardine J, Brooks T et al. (2014) Targeting global protected area expansion for imperiled biodiversity. PLoS Biology 12: e1001891. https://doi.org/10.1371/journal.pbio.1001891

Watson J, Fuller RA, Barr L (2008) Why are we still using a 'one size fits all' philosophy for systematic reserve planning in Australia. Conserv Biol 14: 233–235. https://doi.org/10.1071/PC080233

Watson J, Dudley N, Segan DB, Hockings M (2014) The performance and potential of protected areas. Nature 515: 67–73. https://doi.org/10.1038/nature13947

Wu RD, Zhang S, Yu DW, Zhao P, Li XH et al. (2011) Effectiveness of china's nature reserves in representing ecological diversity. Frontiers in Ecology & the Environment 9: 383–389. https://doi.org/10.1890/100093

Wu RD, Long YC, Malanson GP, Garber PA, Zhang S, Li D, Duo H (2014) Optimized spatial priorities for biodiversity conservation in China: A systematic conservation planning perspective. PLoS ONE 9: e103783. https://doi.org/10.1371/journal.pone.0103783

Wu RD (2016) Conservation: big data boost in China. Nature 540(7631): 38–38. https://doi.org/10.1038/540038c

Xie Y, Chen Y, Zou XY, Wang D, Wang S (1997) Chinese Endangered Species Information System (CESIS). Biodiversity Science 5(4): 293–295. [In Chinese with English abstract]

Zhang LY, Luo ZH, Mallon D, Li CW, Jiang ZG (2016) Biodiversity conservation status in China's growing protected areas. Biological Conservation 210: 89–100. https://doi.org/10.1016/j.biocon.2016.05.005

Zhang L, Xu WH, Ouyang ZY, Zhu CQ (2014) Determination of priority nature CAs and human disturbances in the Yangtze River Basin, China. Journal of Nature Conservation 22: 326–336. https://doi.org/10.1016/j.jnc.2014.02.007